

TN-1446

Technical Note N-1446

THE CEL 100K PROPELLANT ANCHOR - UTILIZATION FOR TANKER MOORINGS IN  
SOFT CORAL AT DIEGO GARCIA

By

D. G. True and R. J. Taylor

July 1976



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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TN-1446	2. GOVT ACCESSION NO. DN587091	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THE CEL 100K PROPELLANT ANCHOR – UTILIZATION FOR TANKER MOORINGS IN SOFT CORAL AT DIEGO GARCIA		5. TYPE OF REPORT & PERIOD COVERED Final; Oct 1974 - Sep 1975
7. AUTHOR(s) By D. G. True and R. J. Taylor		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS CIVIL ENGINEERING LABORATORY Naval Construction Battalion Center Port Hueneme, California 93043		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS Ocean Engineering and Construction Project Office Chesapeake Division Naval Facilities Engineering Command		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS OPN; 42-020
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE July 1976
		13. NUMBER OF PAGES 30
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)  Anchors, Embedment Anchors, Propellant Anchors, moorings, tankers, coral.		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  This report documents the design of the CEL 100K Propellant Anchor, and outlines the mooring requirements and designs as well as the procedures, equipment, and operations involved in installing the propellant anchors and connective gear for tanker moorings at Diego Garcia. This successful installation demonstrated that this type of anchor can be used to advantage in Navy and other applications, particularly where uplift-resistance is desired or where effective anchoring is needed in a hard seafloor.		

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TN-1446      30 p. illus.      July 1976      Unclassified

1. Anchors      2. Embedment anchors      3. Propellant anchors      I. 42-020

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## INTRODUCTION

Reliable long-term moorings over semiconsolidated-to-hard rock seafloors require specialized anchors. Conventional drag-burial anchors are not capable of penetrating consolidated seafloors; the snagging of flukes on outcrops without full penetration cannot be relied upon to provide a durable mooring. Drilled-in anchor piles are commonly used and have proven reliability. The cost of installing drilled-in piles is reasonable when the mooring is situated near a large center of industry where emplacement equipment is available. This cost becomes excessive for a mooring at a remote location.

Two remotely located moorings over a soft coral seafloor were required at the U. S. Naval Communication Station, Diego Garcia (a British territory in the Indian Ocean) for petroleum-oil-lubricant (POL) offloading. One was designated the "temporary" POL mooring, and the other was designated the "permanent" POL mooring. These designations do not necessarily imply the expected use of each mooring because the temporary mooring will probably be used as long as it is functional. The temporary facility, originally completed in 1971, had been scheduled to be replaced eventually by the permanent facility.

The temporary mooring consisted of conventional drag-burial anchors and concrete clumps connected to mooring buoys. This mooring had been dragged on several occasions during high winds, resulting in breakage of fuel pumping lines on three separate occasions, fortunately without vessel grounding or damage.

In 1971, the permanent POL mooring was in the design stage; the selected design consisted of large STATO (drag-burial) anchors, weight clumps, and long lengths of 2-1/2-inch (64 mm) A-link chain. Large propellant anchors were suggested to stabilize the temporary mooring. Shortly thereafter, the design of the permanent mooring was re-evaluated because of its potential susceptibility for similar dragging.

As a result, the CEL\* 100K Propellant Anchor System was selected to secure both tanker moorings at Diego Garcia because of the system's adequate capacity, minimal requirements for peripheral hardware, economy of installation at remote sites, compatibility with onsite installation workboats and equipment, and timely availability. This report documents the design of the CEL 100K Propellant Anchor; outlines the mooring requirements; describes the installation procedures, the mooring designs, and the equipment used to install the moorings; and provides a summary of each anchor installation.

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\* Civil Engineering Laboratory.



This work was sponsored by the Ocean Engineering and Construction Project Office, Chesapeake Division, Naval Facilities Engineering Command, as an augmentation of facility construction under the cognizance of the Pacific Division (PACDIV). Underwater Construction Team One (UCT-One) was responsible for installing the moorings. CEL provided technical representatives to furnish propellant anchor mooring design information to PACDIV, to participate onsite in the mooring installation, and to supervise the operation of the propellant anchor.

## ANCHOR SYSTEM

The CEL 100K Propellant Anchor was developed for the Navy's Supervisor of Diving and Salvage to provide salvage anchoring capability at sites where the seafloor was not suitable for drag-burial anchors. In addition, it was desired that it be capable of operating in unconsolidated sediments so that a single system could be carried aboard a salvage vessel (ARS, ATF, or ATS) for use at any site. The initial version of the system was developed by Aerojet-General under contract to CEL between 1966 and 1968, as documented by Thomason, et al. (1968) and Naval Ships Systems Command (1970). Subsequently, the system was modified to reduce fabrication costs and to improve firing system safety, as described by Smith (1971). Based upon tests of the modified system, the launch vehicle base was strengthened, and anchor projectiles were modified to function similarly to those proven in tests of the smaller CEL 20K Propellant Anchor reported by Taylor (1976).

The anchor system (Figure 1) consists of a launch vehicle, a safe-and-arm (S/A) firing device, a propellant cartridge, a projectile assembly, and lines.

### Launch Vehicle

The launch vehicle consists of a gun mounted atop a quadrapod frame with a square base. It measures about 8 feet (2.4 m) by 8 feet (2.4 m) by 12 feet (3.7 m) high and weighs about 12,000 pounds bare. The gun barrel is a steel forging having the following dimensions:

Item	Dimensions, in. (mm)
Inside diameter	10 (254)
Outside diameter	17 (432)
Overall length	42 (1,067)
Internal travel	36 (915)
Breech diameter (internal upset)	6 (152)

It is designed to operate with a peak pressure of 35 ksi. A breech block is fitted to the breech and screwed in over the propellant cartridge to contain the propellant gases during firing. The outside of the gun barrel is fitted with four double padeyes for pin connection to the quadrapod legs. These legs are bolted to the ends of four beam sections



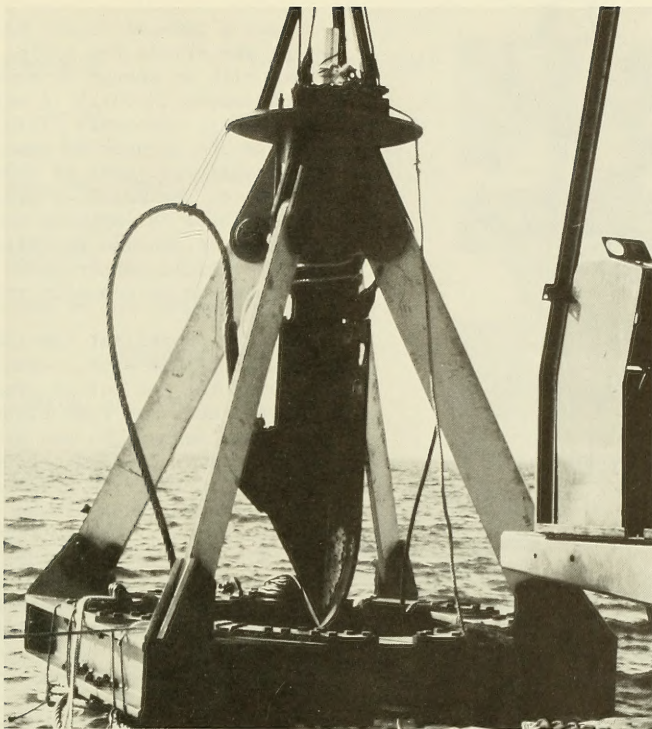


Figure 1. The CEL 100K Propellant Anchor System being deployed, loaded with a coral/sand fluke and a retrievable piston.

that form a square base. The beams support the vehicle and serve as drag surfaces to limit recoil. They must withstand a distributed reaction during firing, peaking at about 2 million pounds (9 MN). Diagonal bracing is attached across the corners of the base providing the strength required to sustain the large outward loading produced by the propellant gases that escape the gun barrel shortly after firing. A circular drag plate is attached to the gun barrel atop the leg eyes. Tie rods are fitted to this plate to secure the projectile assembly before firing.

#### Firing Assembly

Included in the firing assembly are a reusable S/A device and the propellant cartridge.

The S/A device effectively makes the system safe while on deck, arms at a preselected depth, and then causes the system to fire. This device, shown in Figure 2, is screwed into the top of the breech block and contains a firing pin that is driven downward to detonate the propellant charge. An electric current, which must be at least 0.3 ampere at 24 volts, actuates solenoid valves, releasing gas pressure. The gas

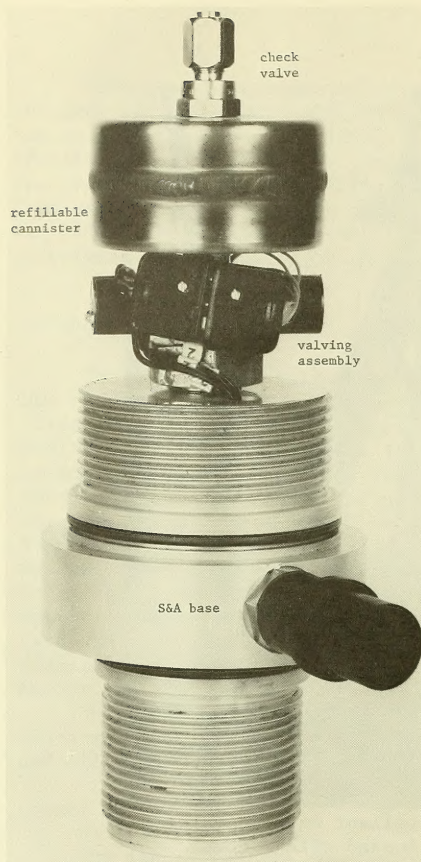


Figure 2. Safe-and-arm device.

breaks a 400-psi (2,800 kPa) shear disk and drives the firing pin downward with an energy in excess of 500 inch-ounces (3.5J).<sup>\*</sup> A safety lock-out plunger prevents firing pin motion unless the plunger is moved in line by a preselected level of hydrostatic pressure. Normally, a separate electrical line is extended to the sea surface to provide actuation, although an on-vehicle battery pack coupled to a touchdown or acoustic trigger could be employed.

The propellant cartridge consists of a cartridge base, capable of containing the gun barrel pressure, a plastic tube and foam plastic plug to contain the charge, and a standard M-58 primer. Firing occurs when the firing pin in the S/A device strikes the percussion cap at the rear (top) of the primer. A peak force of about 2.8 million pounds (12 MN) is generated during firing to act downward on the projectile assembly and simultaneously upward on the launch vehicle.

#### Projectile Assembly

The projectile assembly (Figure 3) includes the piston, shown separately in Figure 4 and the anchor projectile, or "fluke." The dimensions of the flukes are given below:

<sup>\*</sup> M-58 primer detonation requires between 60 and 160 inch-ounces (0.4 to 1.1J).

<u>Dimension</u>	<u>Value for</u>	
	<u>Coral/Sand Fluke</u>	<u>Sand/Clay Fluke</u>
Length, ft (m)	5.5 (1.66)	6.7 (2.04)
Width, ft (m)	2.7 (0.81)	3.3 (1.02)
Thickness, in. (mm)	1 (25)	1 (25)
Weight, lb (kg)	900 (408)	1,250 (567)
Area, ft <sup>2</sup> (m <sup>2</sup> )	12.5 (1.15)	21.5 (1.99)

The dimensions of the piston are given below:

<u>Dimension</u>	<u>Value for Piston</u>
Length, in. (mm)	34.5 (876)
Outside diameter, in. (mm)	10 (254)
Inside diameter, in. (mm)	5.4 (127)
Hollow length, in. (mm)	25.4 (638)
Weight, lb (kg)	700 (320)

The piston is hollow, to accomodate the cartridge; the lower end is fitted with an eye for connection to the piston retrieval line and retainers to maintain proper alignment during firing. It bears against the rear of the projectile, shown in Figure 5, with a peak force during firing of about 2 million pounds (9 MN).

The projectile fits below and is driven by the piston. It may be designed for hard coral or other rock, soft coral, dense sand, or softer unconsolidated sediments. For all but the hardest rock, projectiles are constructed from 1-inch-thick (25 mm) high-strength steel plate. The basic design is a flat anchor plate with a backbone plate to provide strength during installation and service and an eccentric point of attachment to force keying (rotation toward the horizontal). For hard rock, a design similar to that proven effective with the CEL 20K Propellant Anchor in basalt would be used. The projectile assembly is secured in the launch vehicle by tie rods. The lower ends of these tie rods are attached by shear pins through small holes in the rear of the anchor and backbone plates, and the upper ends extend through holes in the barrel dragplate and are secured by nuts atop the drag plate.

#### Lines

Lines are connected to the projectile and piston and are faked in figure-8 loops around timber pads on the bottom of the launch vehicle to allow rapid payout as the projectile assembly is launched downward. The



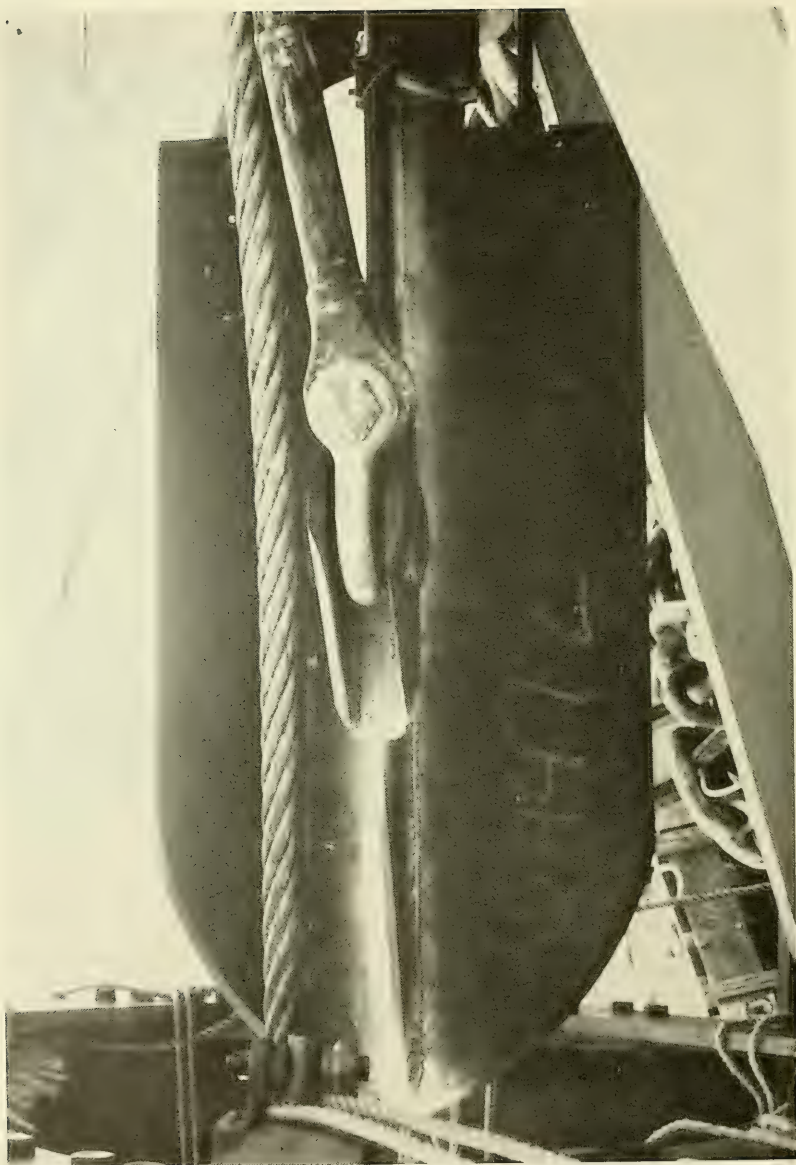


Figure 3. Projectile assembly in gun barrel with anchor load line attached.



main anchor load line is faked on the side of the launch vehicle base adjacent to the eye in the projectile, secured to the acceleration-activated release mechanism on the side of the base, and extended outward toward the intended direction of major loading (if loading will have a lateral as well as an upward component). The piston retrieval line is faked on the opposite side of the launch vehicle base and may be lightly secured to the launch vehicle or extended to the sea surface. The lengths of these lines may be adjusted to fit the water depth, the mooring design, and the connections to be completed after firing by divers or by remote mating devices. The characteristics of these lines as used at Diego Garcia are given below.

<u>Line Characteristic</u>	<u>Value for</u>	
	<u>Anchor Load Line</u>	<u>Piston Retrieval Line</u>
Material	Improved Plow Steel	Extra Improved Steel
Coating	Galvanized	None
Construction	6 x 37 Right Regular Lay With Independent Wire Rope Core	6 x 25 Right Regular Lay With Independent Wire Rope Core
Diameter, in. (mm)	1.75 (44)	1.00 (25)
Breaking Strength, lb (kN)	230,000 (1020)	108,000 (480)



Figure 4. Retrievable piston after use.

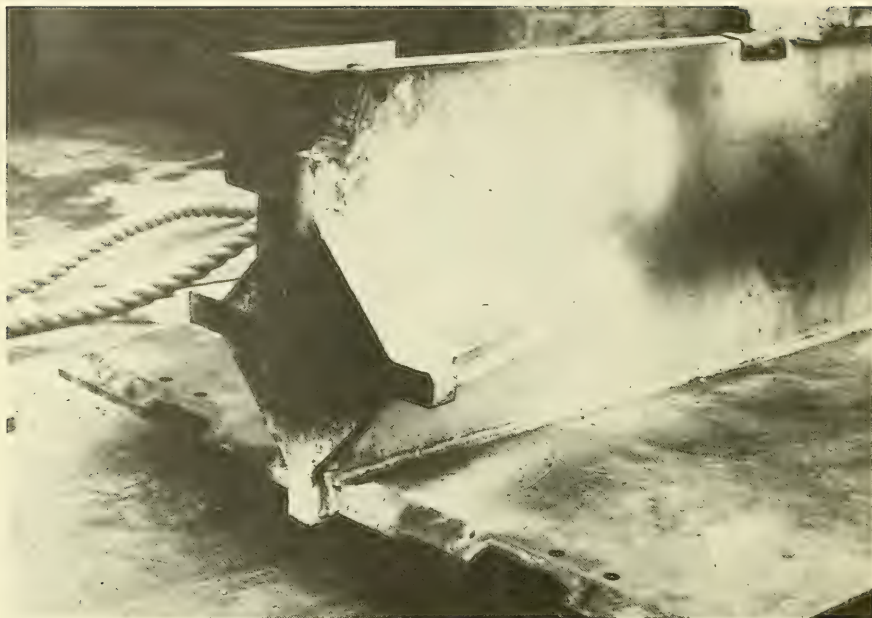


Figure 5. Rear of fluke, showing base plate and holes for shear pins.

#### MOORING DESIGN

Moorings were required on an intermittent to frequent basis for the offloading of POL from tankers. The permanent moor was designated for use by tankers up to and including the AOE-1 SACRAMENTO Class 53,600 dead weight tons displacing (dwt) (54,500 metric tons), whereas the temporary moor was limited to the AO-143 T5 Class, displacing 38,000 dwt (38,600 metric tons). A four-point spread mooring was required at each site in order that ships would remain relatively stationary while offloading fuel into installed submarine pipelines. The moorings were required to be maintained in winds up to 27 knots (14 m/s) with gusts up to 36 knots (19 m/s) and with currents up to 0.5 knot (0.26 m/s) from any direction. In this environment, the maximum forces imposed on a mooring buoy by the vessel in a four-point spread mooring were determined by Fluor Corporation (1973) to be 152,000 pounds (680 kN) for the AOE-1 and 115,000 pounds (510 kN) for the AO-143.

It was required that these moorings be anchored at sites having variable coralline seafloors. Site conditions were reported by operational personnel and confirmed by diver reconnaissance to be coral heads and coral overlain by a loose gravel/sand/silt sediment at the permanent site, and bare coral at the temporary site. The installed conventional drag-burial anchors at the temporary site were not embedded and were visible on the seafloor surface, showing signs of having been dragged without becoming buried. Standard penetration tests conducted in the

area of the permanent site to elevations of about 50 feet (15 m) below sea level indicated very weak cover, this material was removed subsequently by dredging. Diver-operated water-jetted probes revealed 1/2 (.15 m) to 5 feet (1.5 m) of loose cover at most anchor locations at the permanent site after dredging. No data were obtained prior to anchor installation to indicate the strength of the underlying coral at either site. Consequently, anchor projectiles were prepared in two sizes, the smaller for medium-strength coral and the larger for soft and broken coral to provide flexibility in onsite anchor selection to obtain the desired performance.

Experience has shown that propellant anchors are more efficient in harder materials, as indicated by Mayo (1973), Smith (1971) and Taylor (1976). Accordingly, the capacity of the larger projectile in an assumed softest credible material was taken as a lower limit to design capacity. Based upon a buoyant density, measured on grab samples of 51 pcf ( $0.82 \text{ gm/cm}^3$ ) and an assumed friction angle of 30 degrees, this minimum capacity was calculated at 148,000 pounds (660 kN) by the method of Taylor and Lee (1972).

Four-point spread moorings were required to fit the operational needs for POL offloading at Diego Garcia. In order to provide redundancy and an acceptable factor of safety, a leg configuration employing two anchors and a load equalizer was selected. A chain-load equalizer was selected to make use of the ample chain available onsite. Also, the use of chain precluded the wear and fouling problems that might arise if a wire rope running over a sheave were used instead. The tensions on the two ends of the equalizing chain  $T_1$  and  $T_2$  and the tension in the buoy chain  $T_B$  are related as

$$\ln(T_2/T_1) \approx \pi\mu$$

$$T_B \approx T_1 + T_2$$

The approximation is good for small angles between the two opposing portions of the equalizer chain.

Combining to eliminate the smaller chain tension gives

$$T_2 \approx \frac{T_B}{1 + \exp(-\pi\mu)}$$

The factor of safety (F.S.), in terms of known forces, is then

$$\text{F. S.} = H/T_2 \approx \frac{H[1 + \exp(-\pi\mu)]}{T_B}$$

For steel against steel with no galling, the friction coefficient is 0.15, as presented in Carmichael (1950), giving

$$F. S. \approx 1.624 H/T_B$$

If the anchor holding capacity (H) is assumed to be 148,000 pounds (660 kN) (as conservatively estimated above), the factors of safety for the mooring legs at the two sites are as follows:

<u>Site</u>	<u>Design load, T<sub>B</sub>, lb (kN)</u>	<u>F. S. for equalized pair = 1.624 H/T<sub>B</sub></u>
Permanent	152,000 (680)	1.58
Temporary	115,000 (510)	2.08

These values compare favorably with the a priori required factor of safety of 1.5, and also were considered highly satisfactory in view of the high degree of conservatism incorporated into the assumptions of sediment characteristics made in estimating anchor holding capacity.

The general layout of a propellant anchor mooring leg is shown in Figure 6. Legs of this configuration were incorporated into mooring designs, and construction drawings were prepared for the temporary and permanent sites by PACDIV.

The single two-anchor hookup shown in Figure 7 was used at the temporary site. At the permanent site, a short length of chain was added between the buoy and the load equalizer to place the equalizer below the draft depth of ships using the facility. Also, two 750-pound (3.3 kN) LWT anchor backlegs were added to retain the buoys in their desired position when not in use, and a slack backup leg consisting of two 6,000-pound (27 kN) STATO anchors and three shots of chain was added to provide emergency protection in the event of failure of one or both propellant anchors; this configuration is shown in Figure 8. On the turning point leg at the permanent site, four propellant anchors were used, with the outer two connected through an equalizer; the LWT and STATO legs were omitted.

#### INSTALLATION EQUIPMENT AND PROCEDURES

Included in this section are the vessels, shipboard load-handling equipment such as cranes and winches, the diver assistance used to effect installation, and the procedures associated with their use. Details of procedures and equipment were described more fully in the Operation Plan presented by Underwater Construction Team-One (1975); hence, the description given here is intended to summarize and to update that given previously.







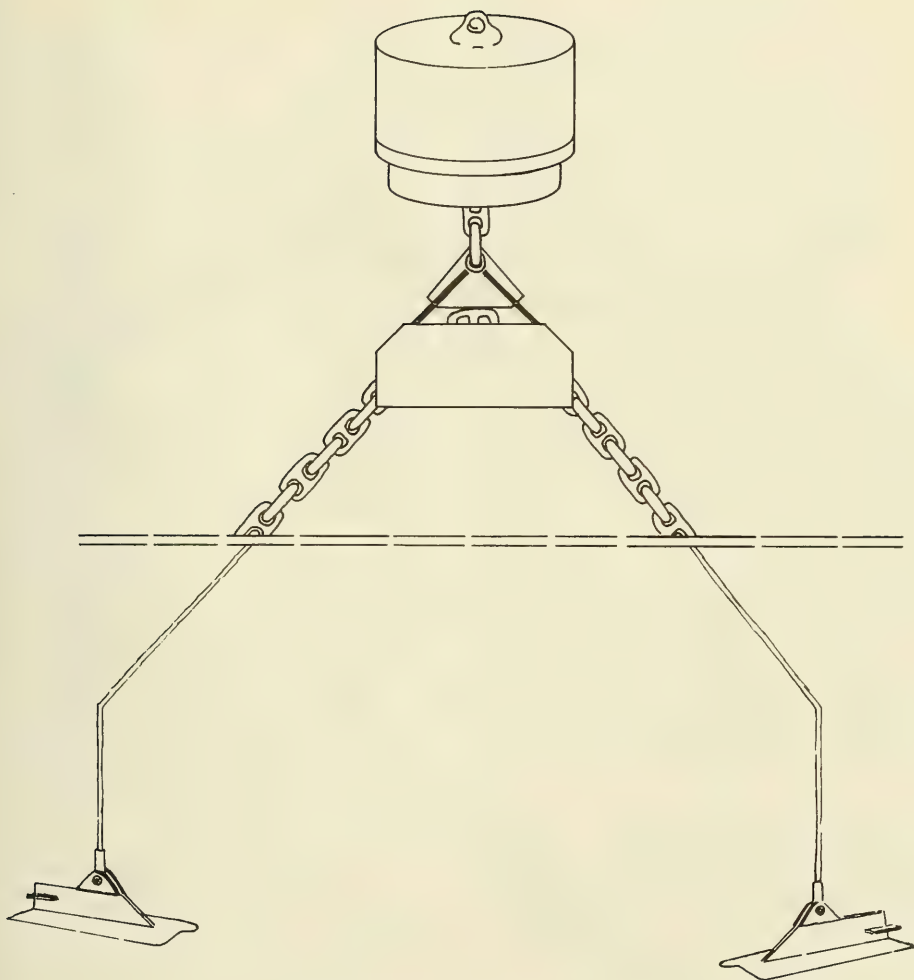


Figure 7. Mooring leg configuration at temporary site.

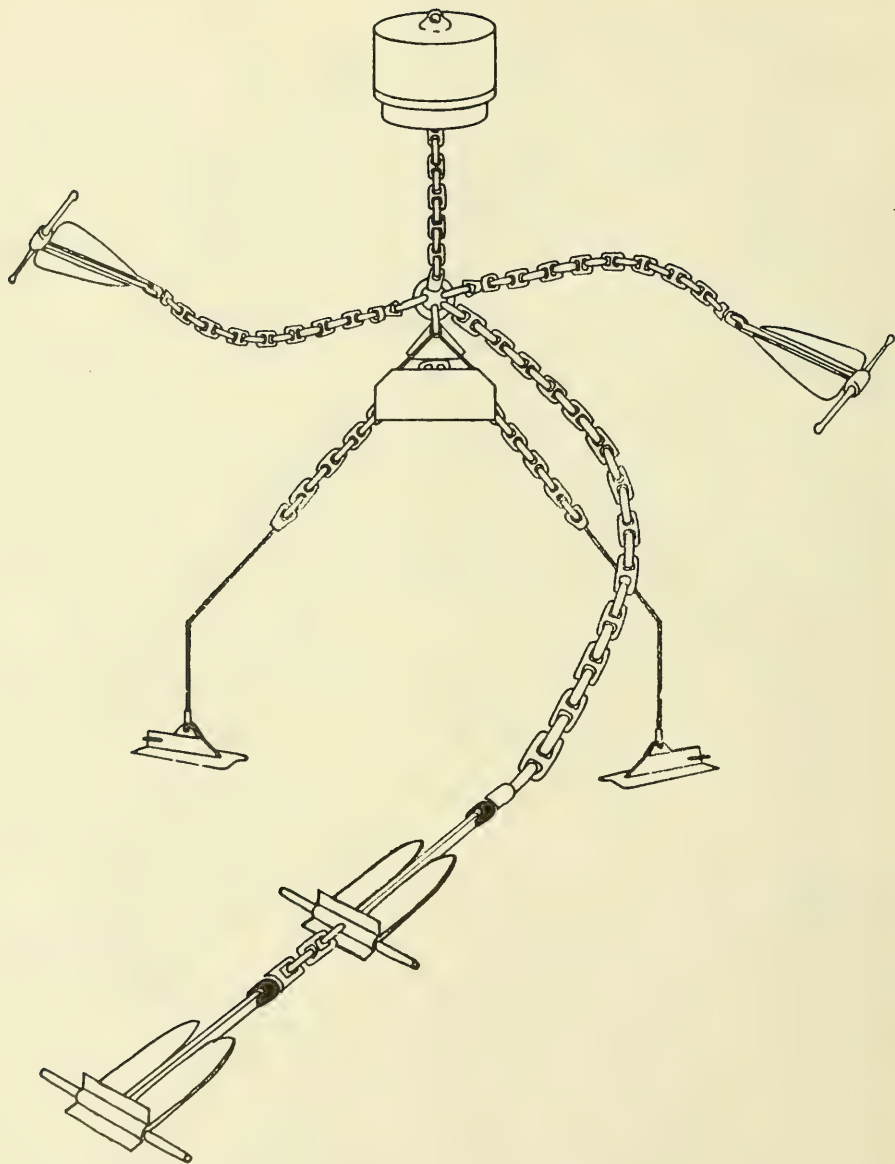


Figure 8. Typical mooring leg configuration at permanent site.



Vessels utilized at Diego Garcia for the reported installation were two YC barges and an LCM-8 workboat. The barges provided working platforms with ample deck space for equipment and anchor hardware. The use of two separate barges provided flexibility to allow an anchor to be installed while a previously installed anchor was being proof-loaded elsewhere. The workboat provided positioning thrust for either or both barges as well as transportation for personnel and additional hardware.

On the "crane barge" was mounted a 30-ton crawler crane fitted with a single-line hook and a four-part hook capable of independent operation. This greatly facilitated tilting of the launch vehicle for preparation. The crane also was essential in lifting the heavy anchor components during assembly operations and was used to retrieve pistons after they had been extracted from the seafloor by the winch barge.

On the "winch barge" were mounted three winches - two smaller ones with 3/4-inch (19 mm) wire and one larger, double drum winch with 1-inch (25 mm) wire and 5/8-inch (16 mm) wire on its two drums. At the opposite end of the winch barge was mounted a 30-inch (760 mm) -diameter roller sheave provided by CEL for proof-loading the anchors without damaging the anchor load line. The main anchor load line was sufficiently long [110 feet] (34 m) that diver assistance was not required, although swimmer assistance was employed frequently to facilitate making connections. This line was retrieved by hauling in on a preattached tag line.

A beach gear purchase section - a nine-part block and tackle designed for applying large loads to anchor lines during salvage operations - was threaded with the 5/8-inch (16 mm) wire from one of the center winch drums to provide the large required proof-loads. A 10,000-pound (45 kN) dynamometer was attached to a stationary block and rigged to deflect the 5/8-inch (16 mm) line through an angle having a sine of about 0.25 to provide load data; this, combined with the nine-to-one mechanical advantage of the beach gear, gave an attenuation factor for the load reading of about 36. The effects of friction were judged to reduce this factor to  $31.5 \pm 1.5$ . Hence, the desired 100,000-pound (450 kN) proof-load was well within the range of the dynamometer. The  $\pm 5\%$  range of precision of this system was considered satisfactory.

A welder was required onboard the barge to secure connections to the anchor projectile after system assembly. Also, onsite modifications to make anchor components mate properly (tie rods to projectiles) required the shipboard use of a cutting torch on each projectile. In addition, a well-stocked toolbox was required for system assembly and adjustment and preparation of the S/A device before each shot.

Briefly, the anchor installation operation began with preparation of the system by fitting the launch vehicle with a piston, a projectile, and lines while it lay on its side. After the launch vehicle was set upright, a cartridge was loaded, the breech block and the S/A device secured, and the firing cable and a safety line for disarming taped in place. The system was deployed by crane to the seafloor at a spot premarked by a small buoy while control was maintained of a tag line attached to the end of the main anchor load line to effect proper

orientation. Deployment is shown in Figure 9. The anchor was then fired, the launch vehicle and the piston were retrieved, and the anchor proof-loaded to at least 100,000 pounds (450 kN). The installation sequence is shown in Figure 10. The connection to proof-loading gear and the subsequent attachment to the chain to complete the mooring hookup were conducted at or above the sea surface.

In order to recover the piston, divers were required to make a connection between the piston retrieval line and a traveling block on the barge's 1-inch (25 mm) wire. This requirement could have been avoided by using a longer line to the piston, or by preconnecting the block or a larger haul-in line to the piston retrieval line before anchor deployment; however, such an approach would have increased the complexity of the deployment operation. The piston retrieval operation was time consuming, even with the ample diver assistance available, and required the use of two winches, the beach gear, and the crane; hence, it was operationally expensive.

With this in mind, the piston retrieval operation was omitted from an early shot, and the satisfactory keying of the fluke and development of holding capacity were verified, at least for the materials at the reported site. Pistons also were not recovered on several of the final installations to save time and to expend the used pistons that were showing some erosion on their outer surfaces due to blow-by of the abrasive propellant. When piston recovery was not attempted, diver assistance was not required.

#### INSTALLATION OPERATIONS SUMMARY

Within 2 weeks, 18 propellant anchors were installed at Diego Garcia, 10 for the permanent POL mooring and 8 for the temporary POL mooring. Two fluke sizes and two types of propellant were used during the installation. A log of the installation operations is in the Appendix. Highlights are discussed below.

Listed in Table 1 are some of the data resulting from the 19 firings. Listed data consist of: installation at either the permanent site or the temporary site (designated by a "P" or "T", respectively), along with the installation order at each site, the nominal fluke size used, the charge weight, the propellant type, the peak gun pressure, the anchor penetration depth, the peak recovery force required to retrieve the piston, and the approximate peak anchor proof-load. Anchors were proof-tested to at least 100,000 pounds (450 kN). Most anchors sustained peak proof-loads between 100,000 (450 kN) and 120,000 pounds (530 kN), although a few of the anchors sustained higher peaks caused by surge, with the highest being 165,000 pounds (730 kN). One anchor was proof-tested statically during calm conditions to 150,000 pounds (670 kN).

Table 1. CEL 100K Propellant Anchor Data for the  
Diego Garcia Permanent and Temporary  
POL Moorings

Date, 1975	Installation Number	Fluke Size, ft (m)	Charge Weight, lb (kg)	Propellant Type	Peak Gun Pressure, ksi (MPa)	Penetration, ft (m)	Peak Piston Recovery Load, klb (kN)	Peak Anchor Proof Load, klb (kN)
22 May	P1	2.7 x 5.5 (0.8 x 1.7)	15 (6.8)	M6	34.0 (234)	35 (10.7)	70	110 (490)
23	P2	2.7 x 5.5 (0.8 x 1.7)	14 (6.4)	M6	33.1 (228)	<b>26</b> (7.9)	*	110 (490)
24	P3	2.7 x 5.5 (0.8 x 1.7)	12 (5.4)	M26	30.1 (208)	35 (10.7)	48 (210)	110 (490)
24	P4	2.7 x 5.5 (0.8 x 1.7)	12 (5.4)	M26	30.1 (208)	35 (10.7)	40-50 (180-220)	110 (490)
25	P5	2.7 x 5.5 (0.8 x 1.7)	12 (5.4)	M26	27.0 (186)	31 (9.4)	90 (40.0)	110 (490)
25	P6	2.7 x 5.5 (0.8 x 1.7)	12 (5.4)	M26	27.0 (186)	35 (10.7)	50 (220)	110 (490)
26	P7	2.7 x 5.5 (0.8 x 1.7)	12 (5.4)	M26	**	30 (9.1)	100 (450)	110 (490)
27	P8	2.7 x 5.5 (0.8 x 1.7)	12 (5.4)	M26	31.7 (219)	30 (9.1)	80 (36,288)	150 (770)
27	P9	2.7 x 5.5 (0.8 x 1.7)	12 (5.4)	M26	31.0 (214)	35 (10.7)	40-50 (180-220)	110 (490)
27	P10	2.7 x 5.5 (0.8 x 1.7)	12 (5.4)	M26	**	31 (9.4)	80 (360)	110 (490)
2 Jun	T1	2.7 x 5.5 (0.8 x 1.7)	12 (5.4)	M26	29.0 (199)	35 (10.7)	30-35 (130-150)	110 (490)
2	T2	3.3 x 6.7 (1.0 x 2.0)	10 (4.5)	M26	25.0 (172)	<b>28</b> (8.5)	30-35 (130-150)	165 (750)
2	T3	2.7 x 5.5 (0.8 x 1.7)	12 (5.4)	M26	29.0 (199)	28 (8.5)	30-35 (130-150)	110 (490)
3	T4	3.3 x 6.7 (1.0 x 2.0)	12 (5.4)	M6	29.0 (199)	28 (8.5)	*	110 (490)
3	T5	3.3 x 6.7 (1.0 x 2.0)	12 (5.4)	M6	29.6 (204)	32 (9.8)	*	110 (490)
3	T6	3.3 x 6.7 (1.0 x 2.0)	12 (5.4)	M6	29.7 (204)	30 (9.1)	*	110 (490)
4	T7	3.3 x 6.7 (1.0 x 2.0)	10.5 (4.8)	M26	28.4 (196)	<b>29</b> (8.8)	*	110 (490)
4	T8	3.3 x 6.7 (1.0 x 2.0)	12 (5.4)	M6	25.3 (174)	30 (9.1)	*	110 (490)

\* Not recovered.

\*\* Not recorded.



Figure 9. Deployment of anchor system, viewed from crane barge looking toward winch barge, with mooring buoy (left foreground) secured to crane barge.

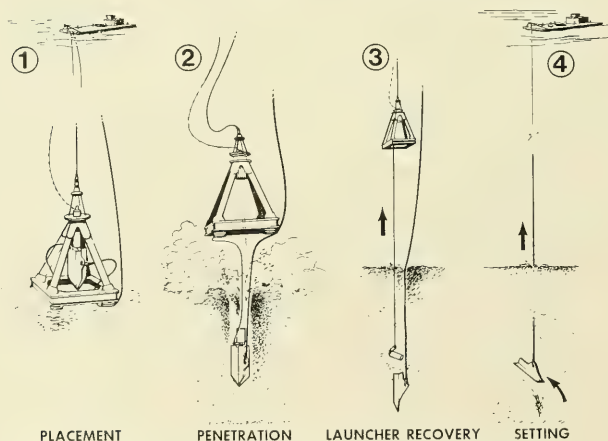


Figure 10. Installation sequence of CEL 100K Propellant Anchor.

Two types of propellant were used, one a slower burning, single-base type (M6) and the other a faster burning, double-base type (M26). The anchor gun system had been designed to be used with the M26; however, computer simulation indicated that satisfactory performance could be achieved with the M6, and its low cost and ready availability made the M6 a very attractive choice. The exact burn rate of the new propellant had not been determined in closed bomb tests. To be safe, reduced charges, which still provided ample performance, were used initially while peak gun barrel pressures were measured with copper crush gages mounted in each cartridge assembly.

Installation P1 (permanent site, anchor no. 1) was fired with 15 pounds (6.8 kg) of M6, producing a peak gun barrel pressure of 34 ksi (234 MPa), somewhat higher than expected. The designed maximum allowable operating pressure for the gun is 35 ksi: (241 MPa) therefore, the use of reduced charges was justified until M6 performance could be accurately defined. Gun barrel pressures derived from M26 firings also were higher than expected. The reason for these differences was attributed to:

1. Elevated burning rates (higher than typical for similar propellant) that may have existed in the untested batches of propellant utilized.
2. A lower-than-calculated chamber volume caused by the large negative tolerances on the inside diameter of the hollow piston that were accepted in order to reduce piston cost.
3. The response of the crush gages to peaks, including the effect of standing wave peaks caused by the nonhomogeneous distribution of the charge within the gun barrel, as opposed to the computer prediction's accounting only for the average pressure at any instant throughout the entire chamber volume.

Once the system was calibrated with a few firings, slight modifications could be made to vary performance with reasonable confidence. This confidence resulted from measured performance repeatability. Charge weights were then varied to yield measured peaks of about 30 ksi (207 MPa). This pressure provided maximum gun life as well as ample energy for installing the flukes so as to achieve holding capacities well in excess of requirements.

Fluke penetration was measured in each case when the anchor load line was taut by subtracting the measured water depth and the measured length of line above water from the entire known line length. This measured line penetration, plus the distance from the connection on the fluke to the fluke tip, yielded fluke penetration to the tip.

The required load to retrieve each piston was recorded. Over the course of the operation, six of the pistons were not recovered. The first expended piston was left in place during installation P2 primarily to determine whether the piston when still in contact with the fluke would affect its performance. This would be particularly important if the seafloor contained large pockets of coral sand/aggregate rather than



intact coral, because the piston could possibly restrict or prevent fluke keying. There appeared to be no discernible degradation in performance. In fact, it is possible that leaving the piston in place enhanced performance if the coral was intact. Pistons were not recovered during the last five installations at the temporary site (T4 through T8). These pistons were well-used, and the piston was not affecting holding capacity; therefore, to save time they were left in place. Piston loads varied from a low of about 30 kips (135 kN) to over 100 kips (445 kN) for pullout. The piston has at most one-fifth the resisting area of the anchor flukes, and it is loaded only at one end. Compared to the centrally loaded flukes, therefore, there is about a factor of 10 between what the piston and fluke should hold. Piston retrieval provided a good basis for judging the ultimate capacity of each anchor fluke. Based upon the piston loads, ultimate holding capacity would vary between 300,000 (1.35 MN) and 1,000,000 (4.45 MN) pounds. The weak link in the system is therefore the anchor cable, which was rated at 230,000 pounds (1.02 MN) minimum breaking strength when new.

The piston load was not solely relied upon to judge anchor performance. Each anchor was proof-loaded to 100 to 120 kips (445 to 535 kN) in direct uplift. One fluke was loaded to 150 kips (670 kN) and another was loaded briefly to 165 kips (735 kN); this latter load was caused by wave surge on the barge.

Three unsuccessful firing attempts occurred because of malfunction of the S/A device, and one installation was delayed by the discovery and correction of a broken circuit in an electrical cable immediately before deployment of the anchor system. The S/A malfunctions were readily diagnosed and remedied by the onsite CEL project engineers. Although the same problems should not recur, such problems are typical of prototypes such as the CEL 100K Propellant Anchor System in its present configuration and should be expected, at a diminishing frequency, in possible future similar operations.

## FINDINGS

### Holding Capacity

Although it is not definitely known at this point, the long-term capacity of the anchors can be inferred from the short-term proof-loading and piston pullout loads.

Based upon the minimum piston pullout load of 30,000 to 35,000 pounds (135 to 155 kN), the respective areas of the piston and the coral/sand fluke, and the respective mechanical advantages associated with pulling on the end of the piston and on the center of the fluke, it is estimated that the short-term capacity is at least 300,000 pounds (1.35 MN); hence, the strength of the main anchor load line (230,000 pounds, or 1.02 MN) is a lower limit to short-term capacity. Each fluke was proof-loaded to over 100,000 pounds (445 kN). This resulted in

vertical movement of the eye in the fluke of 1 to 2 feet (0.3 to 0.6 m). The maximum keying movement (measured as upward line displacement) for developing the ultimate capacity of the 5-1/2-foot-long (1.7 m) coral fluke is about 6 feet (1.8 m) in granular materials. Therefore, a movement of only about 18 to 36% of this maximum brought enough fluke area to bear to develop the proof-load. If the same percentages are assumed to indicate proof-load in terms of ultimate capacity, then this rough data agrees reasonably well with the minimum short-term capacity estimated from the piston retrieval loads - the 100,000-pound (445 kN) proof-load is about 33% of the estimated capacity. Long-term loading, including some component of cyclic loading, might reduce the anchor capacity to a level about equal to the long-term strength of the line (approximately 200,000 pounds, or 890 kN).

### Site Investigation

The site conditions encountered were described as extremely variable, based on data from diver jetting probes. Anchor penetrations varied somewhat, and piston pullout loads varied by more than a factor of two. Anchor setting distances were small, but also varied by a factor of roughly two. Actual capacities are not known. Based upon these data, it is apparent that a suitable site investigation technique, if available, would have the following characteristics:

- a. Tests that indicate sediment strength
- b. A sufficient number of tests for statistical significance
- c. A known relation between anchor penetration depth and test data, to within a factor of 2
- d. A known relation between anchor holding capacity and test data to within a factor of 1.5 or better

These requirements might be satisfied by static- or impact-driven sounding/sampling probes or a small test-type propellant anchor.

At Diego Garcia, it is estimated that an investigation involving one small test anchor at each anchor leg location (a total of eight would be required) would have cost about \$3,000 and could have saved about \$10,000 in costs of fabricating excess projectiles. It is felt that a suitable site investigation technique for remote locations, such as Diego Garcia, should be used to provide a means to specify a priori the optimum cost-effective type and size for anchor projectiles. In this way, performance can be enhanced and costs can be minimized.

### Operations

Operational aspects of the anchor system were very good, especially considering that the crew was initially untrained. In fact, UCT-One personnel indicated that the propellant anchors were much easier to install than conventional drag anchors with their required weight clumps

and long lengths of chain. A UCT-One crew of four men was assigned to work with the two CEL project engineers. After this crew had gained some experience from a few implantments, a comfortable turn-around time of 2-1/2 hours was achieved between two successive anchor implantments, barring complications. Subsequent experience gave sufficient proficiency so that the final two anchors were installed, with no piston retrieval, within a turn-around time of 1-1/2 hours.

The figure-8 method of faking the wire rope anchor load line in a horizontal plane around boards bolted to the base of the launch vehicle proved entirely satisfactory for this large line.

Recovery of the piston after the installation of an anchor fluke is operationally expensive. As piston retrieval is not essential for the anchor to develop its holding capacity in materials similar to those occurring at the reported sites, and as nonrecoverable pistons can be fabricated relatively cheaply, it would appear that for similar installations, it would be uneconomical to recover the pistons. Data must be obtained to verify similar performance in other sediment types before piston recovery can be eliminated generally from the functioning of the system.

After being refurbished and strengthened, the launch vehicle had been used only once prior to its use in Diego Garcia. Therefore, there was some uncertainty about its ability to withstand a large number of firings. A thorough inspection of the system after the 18 shots conducted at Diego Garcia showed no cracked welds or other evidence of damage or distress.

The anchor was fired remotely via an electrical wire to the surface. This method is probably limited to about 500 feet (150 m) of water, and the difficulty and expense of handling the extra line increases with water depth. At Diego Garcia this approach was simple and quick and eliminated the need for a self-contained power supply with a seafloor-sensing triggering device.

Two S/A devices were used during the installations. The solenoid valves and gas cannister assembly were not damaged, as determined by a quick check fire of the assembly after each use.

Three unsuccessful firing attempts occurred because of malfunctions of the S/A device, and one installation was delayed by the discovery and correction of a broken circuit in an electrical cable immediately before deployment of the anchor system. Also, problems occurred with the mating of anchor components. These difficulties were diagnosed and remedied by the CEL project engineers. Had this technical support not been provided, installation of anchors would have been delayed further, and hazardous situations may have occurred. Although the same problems should not recur, problems of similar significance should be expected to occur with diminishing frequency as this, or any other similar prototype is utilized in further installations. In order to provide such an anchor system for operating forces that has no such requirement for technical support, a standardized anchor and installation procedure must be developed and carried through service approval.

The capabilities of large propellant anchors demonstrated in this installation can be used to advantage to satisfy anchoring requirements in the areas of amphibious logistics, tactical expedient POL facilities, undersea surveillance facilities, salvage operations, pollution abatement, fleet moors, ocean facilities construction, and deep sea moors. In many applications in all of these areas, advantages of low cost, light weight, and rapid installation are believed to outweigh the possible disadvantages of providing the required installation support equipment for developing self-contained systems capable of being installed from bare working platforms.

## CONCLUSIONS

From the experiences gained in carrying out the reported installation, the following conclusions are drawn:

1. The propellant anchor provides a cost-effective and time-effective means to anchor permanent moorings of moderate size, particularly in remote locations and where the seafloor is coralline.

2. Operational requirements for the installation of propellant anchor moorings are similar to those for moorings incorporating conventional anchors. In its present configuration, the CEL 100K Propellant Anchor System requires a crane or boom for deployment and retrieval, and a means of applying a large proof-load to the embedded anchor flukes. A double-hooked crane for handling the anchor system and a heavy winch or beach gear purchase section for proof-loading facilitate installation operations.

3. Shorter lines and less connective gear are required for propellant anchor moorings than for conventional moorings, thus reducing costs, staging time, and support requirements.

4. The propellant anchor has good potential for development to satisfy Navy requirements in the areas of amphibious logistics, tactical expedient POL facilities, undersea surveillance facilities, salvage operations, pollution abatement, fleet moors, ocean facilities construction support, and deep sea moors. In many applications it is lighter in weight, easier and quicker to install, and lower in overall cost than other approaches. When desired, it can be used in self-deploying systems having minimal requirements for operational support. Advanced development work is required if the anchor system is to be used by operating forces without technical assistance.

5. It is advisable that a site investigation tool be used to determine the properties of the seafloor material at a site to provide a basis for specifying the optimum type and size of anchor fluke. For soft sediments, the expendable free-fall penetrometer being developed at CEL should suffice. For harder materials such as those encountered at Diego Garcia, a propellant-launched penetrometer or penetrating test anchor might prove satisfactory; such approaches are available but their successful use has not been demonstrated.

6. The CEL 100K Propellant Anchor System with the present configuration of sediment fluke can be used to install embedment anchors having holding capacities in excess of 150,000 pounds (670 kN) applied in any direction. Although ultimate capacities were not determined, long-term capacities were estimated to be on the same order as that of the 1-3/4-inch (44 mm) wire rope used as the main anchor load line (approximately 200,000 pounds, or 890 kN).

7. Expending the piston, rather than retrieving it, appears to be the more cost-effective alternative in most applications. However, the proper keying of the fluke in soft sediments when the piston is not retrieved remains to be demonstrated.

8. The present launch vehicle is durable and reliable, as evidenced by its present excellent condition after nineteen installations. Although not subject to accurate prediction, its remaining useful life is estimated to be well in excess of usage to date.

9. Except as noted in the Appendix, the procedures used and refined during the reported installation appear to be optimum for the system and should be used in future applications. Included especially are the procedures used for system assembly, crane handling, faking of the load line, checking of the S/A device, and firing.

10. Considerable experience with, and knowledge of, the components are required for the successful utilization of the anchor system in its present configuration. This necessitates the availability of CEL technical support. The proposed development of a standardized service-approved anchor and installation method for Navy operating forces would overcome this necessity.

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## Appendix

### ANCHOR INSTALLATION LOG

In the following paragraphs, details are given of the specifics of various installations, particularly those in which problems occurred. Although the functioning problems that were solved should not recur, the progress of the work is typical of what would be expected in a possible future similar operation with such a prototype system.

#### INSTALLATION P1

This installation was the first for the UCT-One personnel, and it understandably went slowly. As personnel became more familiar with the assembly procedures, and handling procedures were improved, subsequent operations went progressively faster. Some components could not be assembled because of improper tolerances. Most components were fabricated and had to be shipped to Diego Garcia without their fit being checked; as a result, some field modifications were required. Most of the first day was expended in making these adjustments and assembling and firing the first anchor. The anchor, placed off the bow of the barge, was supposed to be lowered rapidly to the seafloor but inadvertently was allowed to free-fall in 72 feet (22 m) of water. While this was not intended, in fact it caused considerable excitement, the system landed correctly (upright), was fired by the electrical firing cable that had been retained at the surface, and embedded properly. When the launch vehicle was recovered, it was thoroughly inspected for any weld cracks or structural deformations; there were none.

#### INSTALLATION P2

The anchor was assembled in about 2-1/2 hours and placed on the seafloor. The anchor did not fire and was left on the seafloor for 30 minutes in case there was a hangfire. It was then brought to the surface and inspected; it was in a safe status as evidenced by the hydrostatically enabled mechanical interlock in the S/A device being in the out-of-line (safe) position. The S/A device was inspected; the gas cannister, which provides the energy to drive a firing pin into the primer located in the cartridge assembly, was discovered to be empty. It had been filled with dry air to a pressure of 1,100 psi (7.6 MPa) but apparently the one-way valve in the cannister did not close after filling and the pressure bled before the unit could be placed in a dielectric fluid to check for slow leakage.

Possible recurrence was prevented by check-measuring the outside length of each cannister, when empty and when filled, with a sensitive micrometer. The cannister would be measured as it was being filled and just prior to installing it in the S/A device. This proved entirely satisfactory and is very simple to perform.

A new S/A device was placed in the anchor, and it was placed back on the seafloor. The anchor was fired and test-pulled satisfactorily.

There was sufficient time to install another anchor that day, but the process of getting the YC barge into its STATO mooring was too time consuming, and the firing was delayed until the following morning. Because of this problem, it was decided to use the LCM8 to position the YC barge over the drop point for a new mooring leg and then to use the first installed anchor to hold the barge for the second firing. This procedure worked very well, and greatly sped up the operation.

#### INSTALLATION P3, P4

Both firings produced almost identical results. Gun barrel pressure, penetration and piston retrieval load were similar. Both firings occurred on one day and each anchor took about 2 to 2-1/2 hours to assemble and deploy.

#### INSTALLATION P5

The anchor was placed on the seafloor, and it could not be fired because of an open circuit on one side of the firing cable (this is easily detected because the resistance through the firing cable and solenoid valves in the S/A device is accurately known). Line resistance was about 200 ohms compared to the correct resistance of 70-80 ohms, indicating a correct electrical connection to only one solenoid; thus the system could not fire with the existing (safe, 36-volt) power supply. The anchor was immediately brought on deck; misfire procedures were unnecessary in this case, and the wire was replaced. The problem was simply a dirty connector. Standard procedure had been to check the line resistance at several stages during assembly and overbearing, but this problem did not occur until the anchor was in the water. The wire was replaced and the anchor was quickly fired and test-pulled.

#### INSTALLATION P6, P7

Both anchors were installed without incident. One notable point was that the piston retrieval load for P7 was 100-110 kips. The piston alone in this case would have provided sufficient resistance to serve as the primary mooring anchor. Gun barrel pressures for both firings, each using 12 pounds (5.4 kg) of M26 were identical, 27 ksi (186 MPa). These pressures were consistently higher than originally predicted, but their excellent repeatability allowed slight field changes to obtain desired field performance.

## INSTALLATION P8

This installation was marked by a problem with the S/A device. The anchor did not fire and was brought to the sea surface after 30 minutes to inspect the safe status of the anchor. It was completely safe, the in-line/out-of-line plunger in the S/A device was completely out of line. Upon disassembly, it was found that the S/A device had been activated, and the firing pin was driven against the plunger. The plunger did not go in line. The plunger was supposed to be completely in line at a depth of 35 to 40 feet (11 to 12 m). The water depth was 72 feet (22 m), and the plunger had not even moved. The reason became apparent when the S/A was again screwed into the breech. Pressure built up between the S/A base and cartridge base because there was considerable grease on the S/A threads preventing pressure relief. This problem was rectified by filing a V groove across the S/A threads to allow pressure relief; this problem did not recur. A grooved S/A device was installed, the anchor replaced on the seafloor, and fired. The anchor was proof-loaded to 150 kips (670 kN).

## INSTALLATIONS P9, P10, T1

Each anchor was fired and test-pulled to 100 to 120 kips (445 to 535 kN). Total assembly time was now reduced to about 1-1/2 to 2 hours.

## INSTALLATION T2

The large 3-1/2 x 7-foot (1.0 x 2.0 m) fluke was used for the first time. When installed in the gun system, the fluke rests about 2 inches (50 mm) above the seafloor. There was concern that gun barrel pressures could increase when the fluke contacted the competent coral prior to the piston fully leaving the barrel. This concern was rapidly abated after this firing because the penetration depth and the measured peak gun pressure were similar to those experienced at the permanent site and were close to what would be expected for any unlithified seafloor. This fluke was statically loaded to 100-120 kips (445 to 435 kN); however, the load did jump to 165 kips (735 kN) for a brief period because of wave action on the YC barge. There was no noticeable fluke movement.

## INSTALLATION T3, T4, T5

All three anchors were installed rapidly and test-pulled to 100 to 120 kips (445 to 535 kN). In order to save time, the last five pistons, used with anchors T4 through T8, were not recovered. Each piston had been used previously; and, as leaving them in place apparently had no adverse effect upon anchor holding capacity, they were not pulled.

#### INSTALLATION T6

The anchor didn't fire the first time down. The water depth was 47 feet (14.4 m) instead of the 60 feet (18 m) measured 50 feet (15 m) away. The safety plunger prevented firing in that shallow depth. Therefore, a new, weaker spring was installed in the S/A device and the anchor was returned to the seafloor, fired, and test-pulled.

#### INSTALLATIONS T7, T8

Both anchors were installed and tested within a 1-1/2-hour time period. The first anchor was almost completely assembled the previous night and loading the cartridge and installing the S/A were all that were required. However, the 1-1/2-hour total turn-around time that elapsed between firings was indicative of how the crew's familiarity with the system had progressed.



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